

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 15

CAPACITANCE EXPERIMENTS

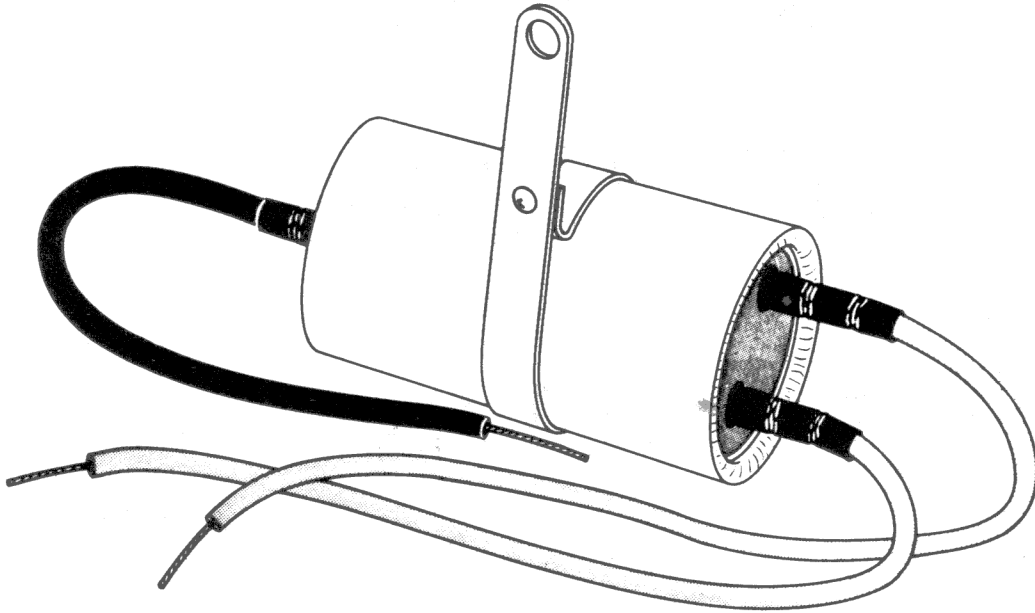


RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

*electrolytic capacitor*

All the parts in Kit 8 are listed below. Check the parts you receive against this list. Make sure you have the correct quantity of every item. If a part is either missing or defective upon arrival, request a replacement from Department R, Home Study School, RCA Institutes, Inc., 350 West 4th Street, New York 14, N.Y. Your request must include your name and student number, the complete name and description of the part copied from the Item column below, the Quantity missing or defective, and the reason you are asking for a new part.

KIT 8**BILL OF MATERIALS**

Quantity	Item
1	Audio choke, 12h
30	#6 ground lugs
30	#6 x 3/8" wood screws
1	Electrolytic capacitor, 20 μ f x 20 μ f x 250 volts
1	Capacitor, 0.01 μ f, 400 volts
2	Capacitors, 0.02 μ f, 400 volts
4	Capacitors, 0.05 μ f, 400 volts
2	Capacitors, 0.1 μ f, 400 volts
1	Capacitor, 0.25 μ f, 400 volts
1	Resistor, 1,000-ohm 2-watt BRN BLK RED SIL
1	Resistor, 1,000-ohm 5-watt WIREWOUND FLAT-TAN,
2	Resistors, 100 k-ohms, 1/2-watt BRN BLK YEL SIL
1	Resistor, 3.3 megohms, 1/2-watt BRN BLK YEL SIL

Experiment Lesson 15

OBJECT

1. To study the effect of capacitors in d-c circuits.
2. To study the effect of capacitors in a-c circuits.
3. To study a method of measuring the capacitive reactance and capacitance of capacitors.

PREPARATION

Check your parts against the bill of materials on page 2. Any parts not used in this lesson should be placed aside for use in future lessons.

Before beginning these experiments, read and study Theory Lesson 15. Do these experiments after you are sure you understand the theory of capacitors. Try to account for everything that you observe while doing the experiments. If you come across something that puzzles you, go back to the Theory Lesson for an answer.

In this lesson you will make a capacitor breadboard from a piece of wood, 9 x 12 inches.

EQUIPMENT NEEDED

Battery composed of four 1.5-volt cells in series

Multimeter

10,000-ohm 1/2-watt resistor

Receiver chassis

Pilot-light socket

Neon bulb

Shielded test lead with clips (made in Experiment Lesson 2)

Tools

9 x 12-inch board

Twenty-eight #6 soldering lugs

Twenty-eight 1/4-inch wood screws

Ten capacitors:

One 0.01 μ f

Two 0.02 μ f

Four 0.05 μ f

Two 0.1 μ f

One 0.25 μ f

JOB 15-1

To prepare the capacitor breadboard for mounting the capacitors.

Procedure.

Step 1. On a 9- x 12-inch board, mark 28 points for mounting soldering lugs, as shown in Fig. 15-1.

Step 2. Mount the lugs as shown in Fig. 15-2. Note that one pair of lugs is shown pictorially, so that you'll know just which way they face as you mount them. The other lugs are just shown by a symbol.

EXPERIMENT 15-1

To study the charge-holding ability of a capacitor.

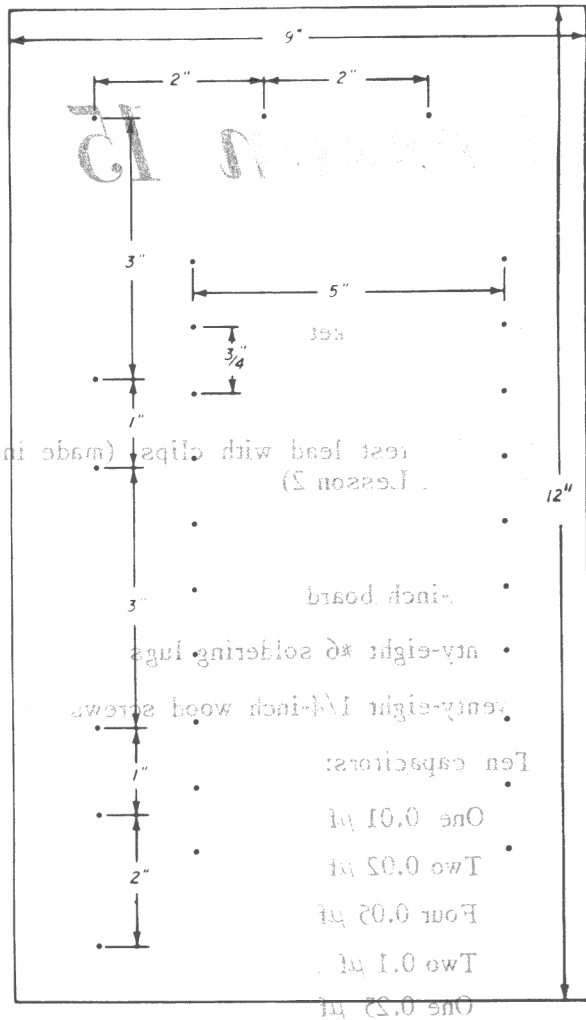


Fig. 15-1

Warning: Be careful when you handle capacitors. In this lesson and in lessons to come, you can shock and hurt yourself if you don't take special care when working with capacitors. The most dangerous thing about a charged capacitor is that the rate of discharge is limited only by the resistance of the discharge path. When your body touches the terminals of a charged capacitor, the rate of discharge depends on the resistance of the part of your body that is between the terminals. Sometimes this resistance is very low; the discharge current is then very high. Don't take chances. Handle charged capacitors with care and do not touch the terminals or terminal leads unless you know that the capacitor is discharged.

Procedure.

Step 1. Connect the a-c line from the

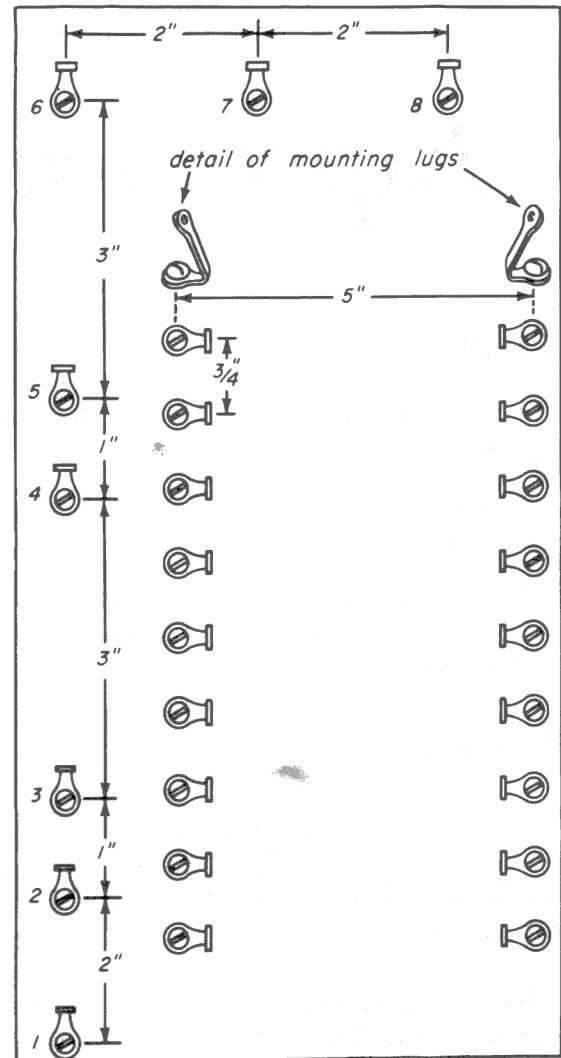


Fig. 15-2

power-line terminal strip on the receiver chassis to soldering lugs 1 and 2 on the capacitor breadboard with hook-up wire, as shown in Fig. 15-3.

Step 2. Solder the pilot lamp socket to soldering lugs 3 and 4 on the wooden board, as in Fig. 15-3, and insert the neon lamp into the socket.

Step 3. Connect the a-c plug to an a-c outlet.

Step 4. Hold the 0.25- μ f capacitor carefully in the center of its body, as shown in Fig. 15-4, keeping your fingers well away from the leads. Touch the capacitor across the a-c line for a moment.

Step 5. Carefully touch the capacitor

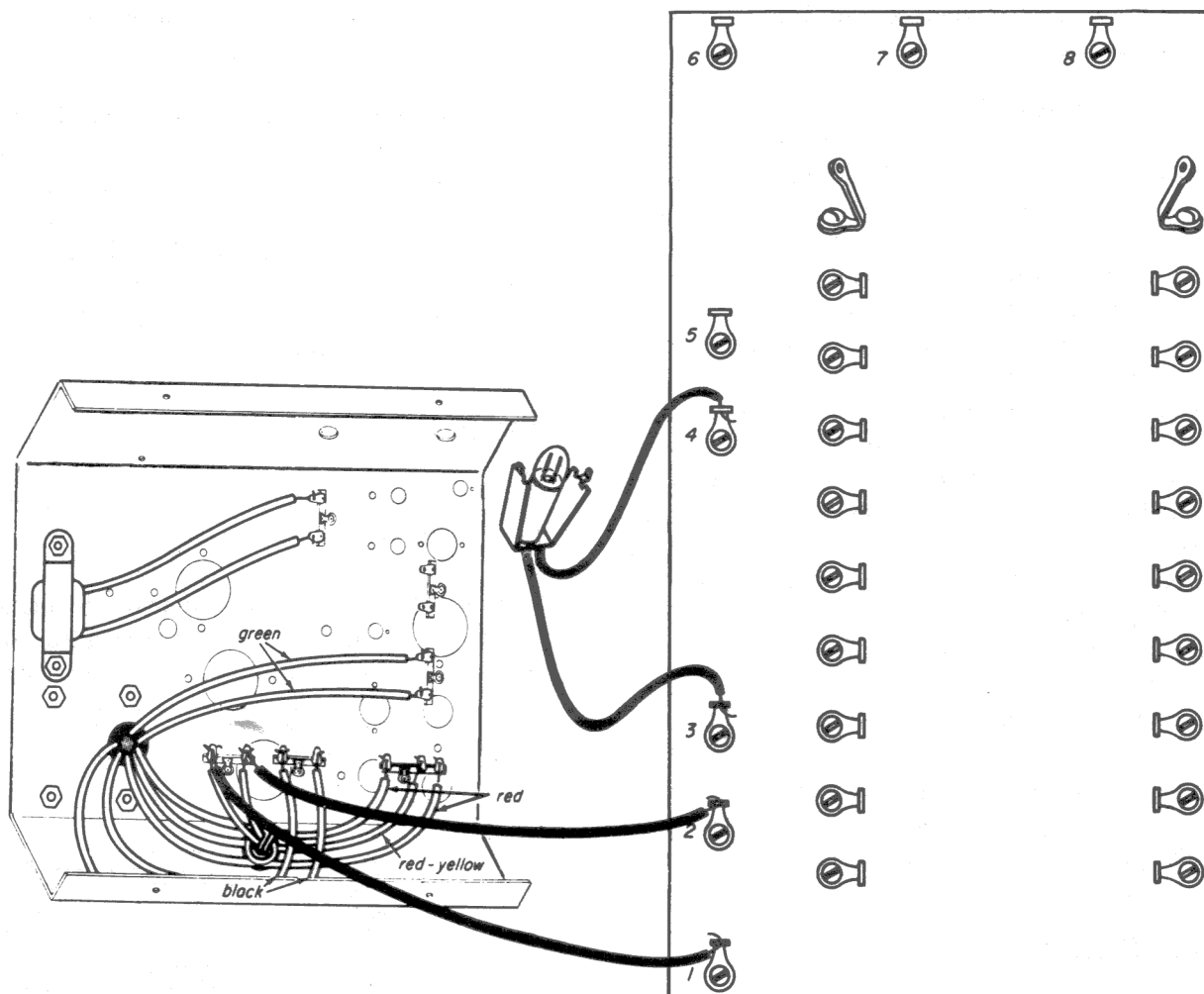


Fig. 15-3

across the soldering lugs to which the neon lamp is connected. *Do not touch the capacitor leads.* Note the effect. Do this several times.

Step 6. Unsolder the pilot-lamp socket from the capacitor breadboard.

Step 7. Set your multimeter to the 100 VDC range.

Step 8. Plug the phone tips of the shielded test lead into the red and black jacks of your meter. Clip the test leads to soldering lugs 3 and 4.

Step 9. Hold the 0.25- μ f capacitor carefully in the center of its body, as before — keeping your fingers well away from the leads. Touch the capacitor across the a-c line for a moment.

Step 10. Carefully touch the capacitor across the two lugs to which the meter leads

are connected. The meter may read backward or not at all. If the meter reads backward, *do not* change the meter connections.

Step 11. Repeat Steps 9 and 10 a half-dozen or more times. Note the direction and the amount of the momentary meter reading.

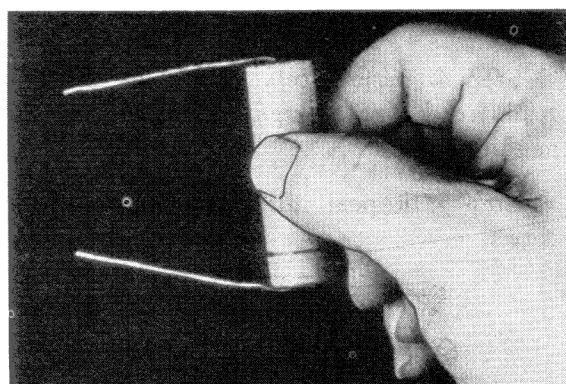


Fig. 15-4

Step 12. Disconnect the line cord from the a-c outlet.

Discussion. This experiment demonstrates the ability of capacitors to store a charge of electricity. The amount of charge that the capacitor will have in Step 9 depends upon the instant of the a-c cycle at which the capacitor is removed from the a-c line. If the capacitor is removed just at the instant when the a-c voltage is going through a positive maximum, the capacitor will be charged, in one direction, to the peak value of the applied a-c voltage. When the capacitor is connected to the meter lugs, the meter needle will go up scale or down scale, depending on how the capacitor leads are connected to the meter lugs. If it is removed during the negative maximum, the meter needle will move in the opposite direction (if the capacitor leads are connected to the meter lugs in the same way). If the capacitor is removed at the instant when the a-c voltage is going through zero (which it does twice during each cycle), it will have no charge and cause no movement of the meter needle.

EXPERIMENT 15-2

To study one effect of dielectric absorption.

Procedure.

Step 1. Plug the line cord into the a-c outlet.

Step 2. Charge the $0.25\text{-}\mu\text{f}$ capacitor by placing it across the a-c line as before.

Step 3. Discharge the capacitor by placing both leads against the metal chassis for a moment.

Step 4. Immediately touch the capacitor leads to the meter lugs and watch the meter needle.

Step 5. Repeat this experiment several times.

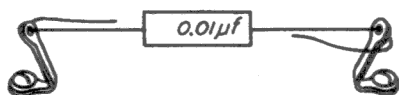


Fig. 15-5

Step 6. Disconnect the line cord from the a-c outlet.

Discussion. If this experiment is performed correctly, and if the capacitor receives a high charge from the a-c line, the meter needle will flicker even after the capacitor is discharged. The slight meter reading after discharge shows a single charge on the plates caused by the dielectric giving up its absorbed charge.

JOB 15-2

To wire the capacitors to the capacitor lugs on the breadboard.

Note: The lugs are spaced 5 inches apart. The total length of capacitor and leads may, in some cases, be more than 6

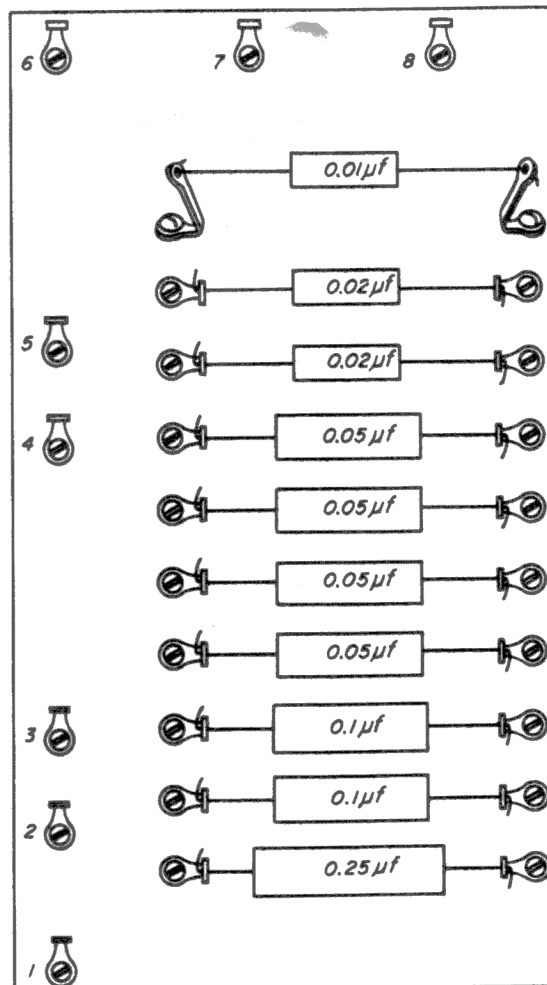


Fig. 15-6

inches. Even so, do not cut any of the capacitor leads. Instead, center them between the lugs and bend the ends into a hook, as shown in Fig. 15-5. Then solder them temporarily; later in this course, you will use the same capacitors in your receiver and signal-generator circuits.

Procedure.

Step 1. Wire the capacitors in the exact order shown in Fig. 15-6.

Step 2. Check each soldered joint to make sure that each is firmly soldered.

EXPERIMENT 15-3

To study the flow of alternating current in a capacitive circuit.

Method. In this experiment, you will wire the circuit as shown in the pictorial diagram, Fig. 15-7. You will then measure the circuit voltages to learn how the applied a-c voltage divides across the capacitor and the resistor.

Procedure.

Step 1. At the a-c line-cord terminal strip, remove the leads that connect it with lugs 1 and 2 of the capacitor board and connect these leads to the 6-volt secondary terminal strip, as shown in Fig. 15-7.

Step 2. Connect the a-c line-cord terminal strip to the transformer primary terminal strip, using hookup wire.

Step 3. Connect the 10,000-ohm resistor between lugs 3 and 4 on the capacitor board.

Step 4. Connect the 10,000-ohm resistor

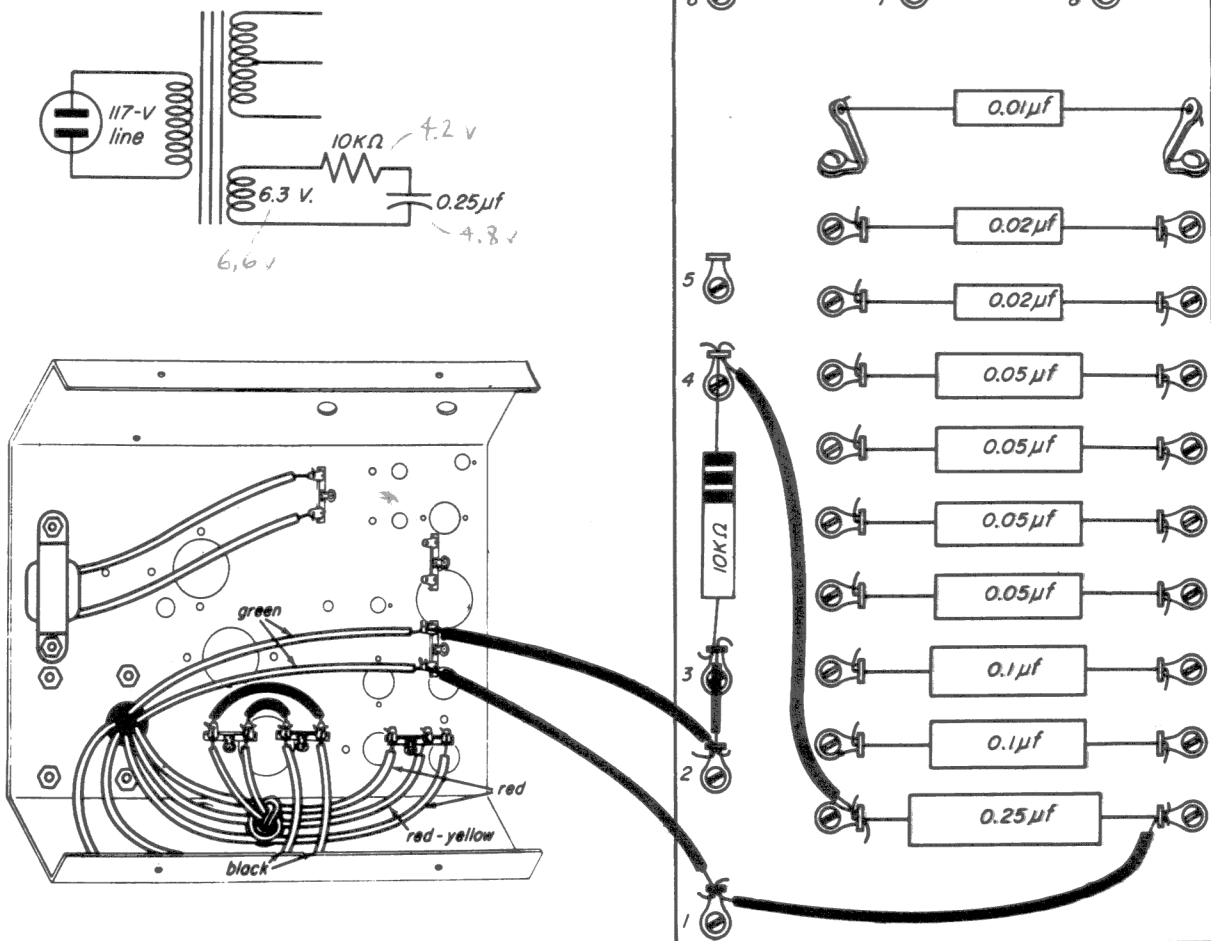


Fig. 15-7

and the 0.25- μ f capacitor in series, as shown in Fig. 15-7.

Step 5. On the capacitor board connect lug 2 with lug 3 and lug 1 with the free end of the 0.25- μ f capacitor.

Step 6. Check your wiring to see that it agrees with that shown in Fig. 15-7. Then connect the line cord to the a-c outlet.

Step 7. Measure the a-c voltage across the resistor and record it here:

4.2 volts a.c.

Step 8. Measure the a-c voltage across the 0.25- μ f capacitor and record it here:

4.3 volts a.c.

Step 9. Measure the a-c voltage across the 6-volt secondary and record it here:

6.6 volts a.c.

Step 10. Disconnect the line cord from the a-c outlet.

EXPERIMENT 15-4

To study the d-c blocking action of a capacitor.

Method. In this experiment you will apply 6 volts d.c. to the circuit instead of the a-c voltage that you applied in the last experiment. Then you will measure voltages as before.

Procedure.

Step 1. Remove the leads that connect lugs 1 and 2 of the capacitor board to the 6-volt secondary terminal strip.

Step 2. Clip the 6-volt battery to ter-

minals 1 and 2 of the capacitor board. The circuit should look like that in Fig. 15-8.

Step 3. Measure the voltage across the battery and record it here:

6.4 volts d.c.

Step 4. Measure the voltage across the resistor and record it here:

0 volts d.c.

Step 5. Measure the voltage across the capacitor and record it here:

6.2 volts d.c.

Step 6. Disconnect the battery from the circuit.

Step 7. Discharge the capacitor.

Discussion. These short experiments demonstrate one of the most important uses of capacitors in radio and electronic circuits — to block d-c voltages but allow a-c voltages to pass. Most of the circuits in radio and television receivers contain d-c and a-c voltages in series. As you have seen from your measurements, the capacitor blocks the d-c voltage from appearing across the resistor; you found that the entire d-c voltage present in the circuit appears across the capacitor. Thus, the voltage rating of the capacitor used as a d-c blocking capacitor must be at least equal to, or better still, higher than, the d-c supply voltage present in the circuit.

From your measurements in Experiment 15-3, you are able to see that not all of the a-c voltage appears across the resistor, but that some of the a-c voltage is developed across the capacitor, due to its capacitive reactance. This is undesirable, because only

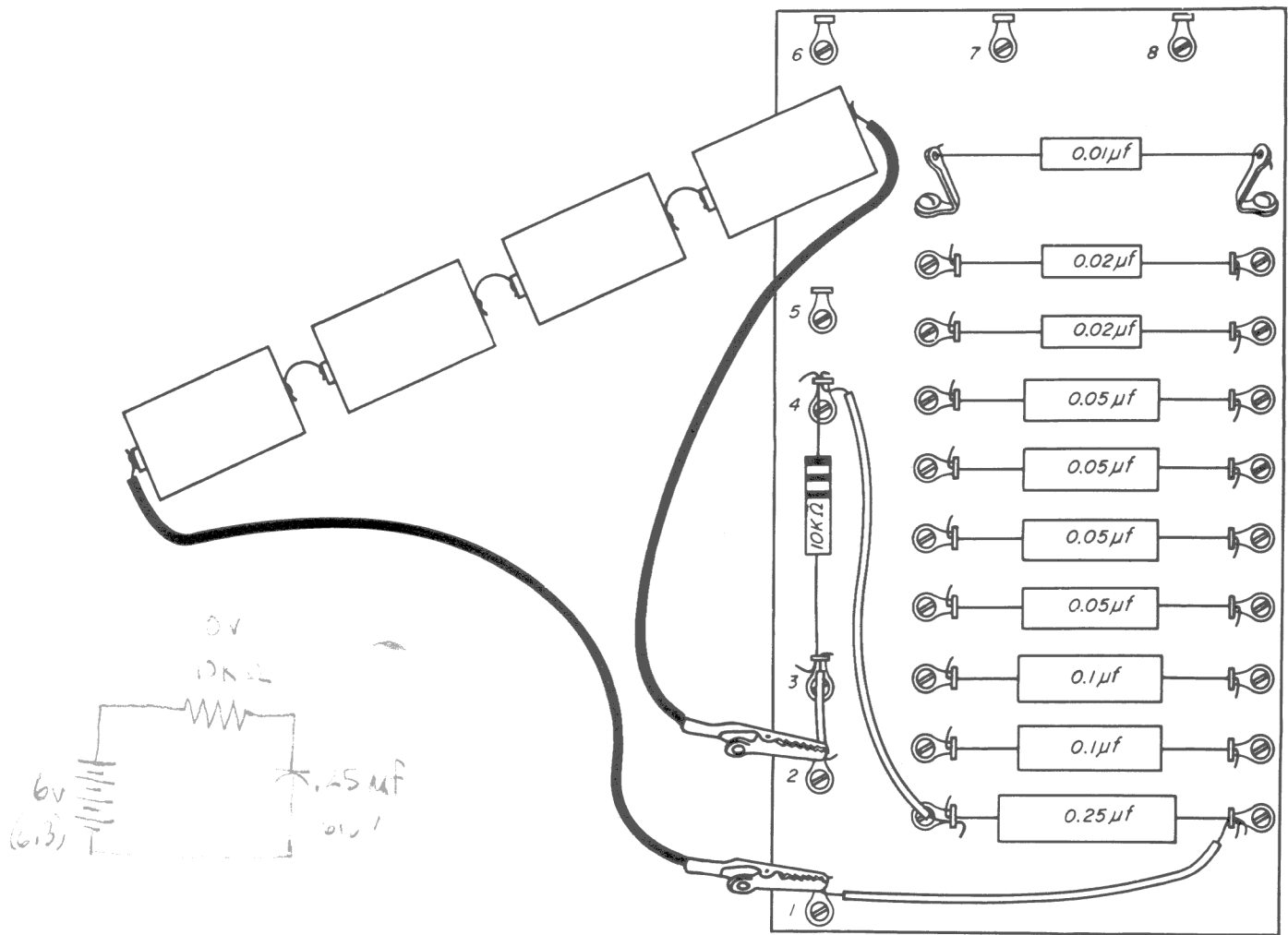


Fig. 15-8

the voltage developed across the resistor can be used in an amplifier. Therefore, a large-value capacitor is usually used as a d-c blocking capacitor so that reactance will be low and only a small part of the signal voltage will be lost across it.

EXPERIMENT 15-5.

To measure the capacitive reactance and capacity of a capacitor.

Method. You will connect the 10,000-ohm resistor and a 0.01- μ f capacitor in series across the a-c power line, as in Fig. 15-9. Then you will measure the a-c voltage division and calculate the current, the capacitive reactance, and the capacity of the capacitor.

Procedure.

Step 1. At the 0.25- μ f capacitor, disconnect the lead that connects it with the resistor and solder it instead to the 0.01- μ f capacitor, as shown in Fig. 15-9.

Step 2. Remove the leads that connect the transformer-primary terminal strip with the line-cord terminal strip.

Step 3. Connect one end of the line-cord terminal strip to Lug 1 on the capacitor board.

Step 4. Connect lug 2 on the capacitor board with the open end of the line-cord terminal strip.

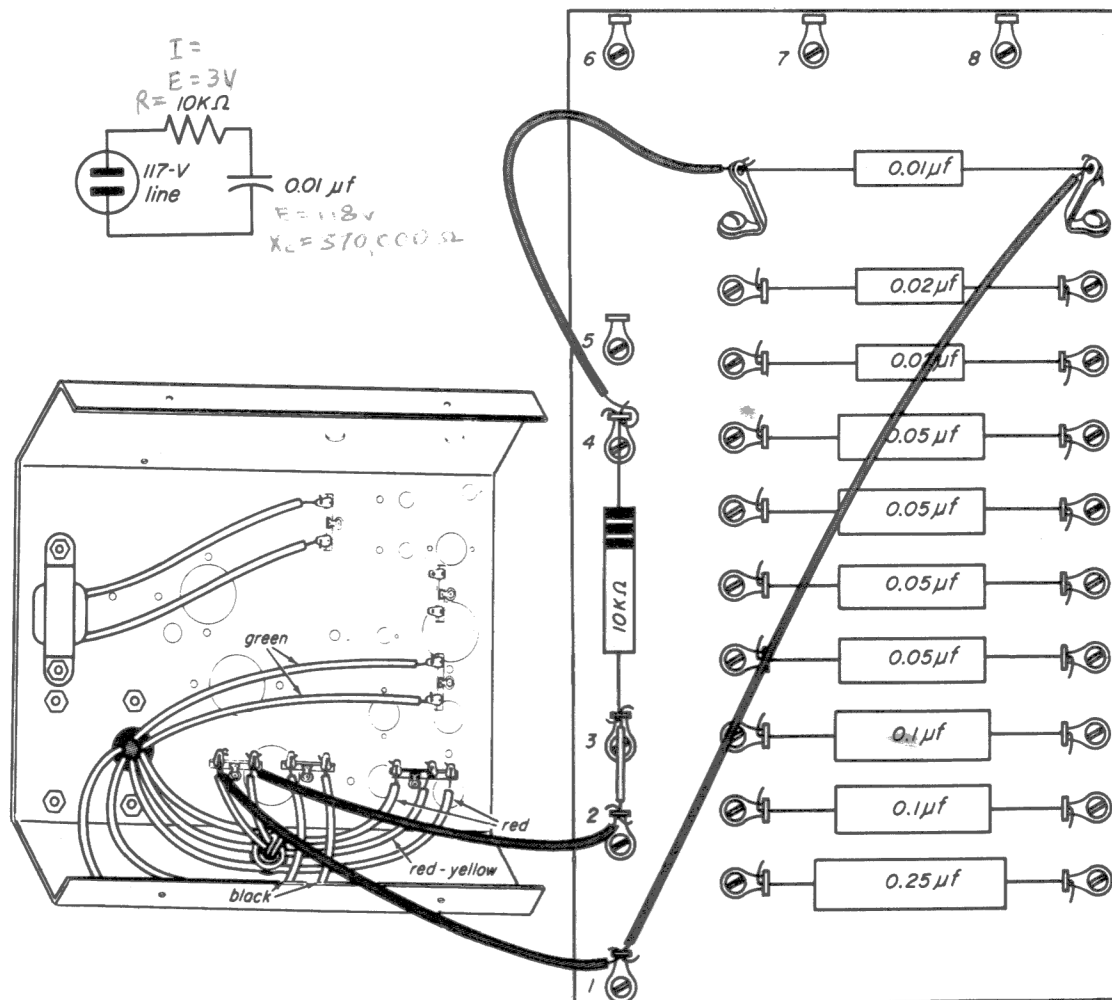


Fig. 15-9

Step 5. Connect lug 1 on the capacitor board with the free end of the 0.01- μ f capacitor.

Step 6. Check your wiring with Fig. 15-9 and then plug the line cord into the a-c outlet.

Step 7. Using the 300 VAC range of your multimeter, measure the voltage across the resistor and record it here:

3 volts a.c.

Step 8. Measure the voltage across the capacitor and record it here:

118 volts a.c.

Step 9. Disconnect the line cord from the a-c outlet.

Step 10. Discharge the capacitor.

Step 11. Calculate the current in the circuit, using the formula:

$$I = \frac{E_R}{R} = \frac{3}{10,000} = .0003$$

Record the answer here:

.0003 amp

Step 12. Calculate the capacitive reactance of the capacitor, using the formula:

$$X_C = \frac{E_c}{I} = \frac{118}{.0003}$$

Record the answer here:

370,000 ohms

Step 13. Calculate the capacity of the capacitor, using this formula:

$$C = \frac{159,000}{f \times X_C} = \frac{159,000}{60 \times 37 \times 10^3} =$$

Record the answer here:

.001 μ f

Compare the value of capacity that you calculated with the value marked on the capacitor. The two values should be within 20 percent of each other.

Discussion. Based on a line voltage of 110 volts, your results will be approximately as follows:

Voltage across resistor	4 volts
Voltage across capacitor	108 volts
Current through circuit (calculated)	0.0004 amp
Capacitive reactance (calculated)	270,000 ohms
Capacitance (calculated)	0.01 μ f

EXPERIMENT 15-6

To study how capacitive reactance varies with capacity.

Method. In this experiment you will connect a 0.05- μ f capacitor in place of the 0.01- μ f capacitor, measure voltages, and calculate the reactance and capacity as in Experiment 15-5.

Procedure.

Step 1. Connect the 10,000-ohm resistor and a 0.05- μ f capacitor in series with the a-c line, as shown in Fig. 15-10.

Step 2. After checking your circuit, connect the line cord to the a-c outlet.

Step 3. Measure the voltage across the resistor and record it here:

22 volts a.c.

Step 4. Measure the voltage across the capacitor and record it here:

118 volts a.c.

Step 5. Disconnect the line cord from the a-c outlet and discharge the capacitor.

Step 6. Calculate the current in the circuit, using the following formula:

$$I = \frac{E_R}{R} = \frac{22}{10,000} = .0022$$

Record the answer here:

.0022 amp

Step 7. Calculate the capacitive reactance of the capacitor, using the following formula:

$$X_C = \frac{E_C}{I} = \frac{118}{.0022}$$

Record the answer here:

53,630 ohms

Step 8. Calculate the capacitance of the capacitor, using the following formula:

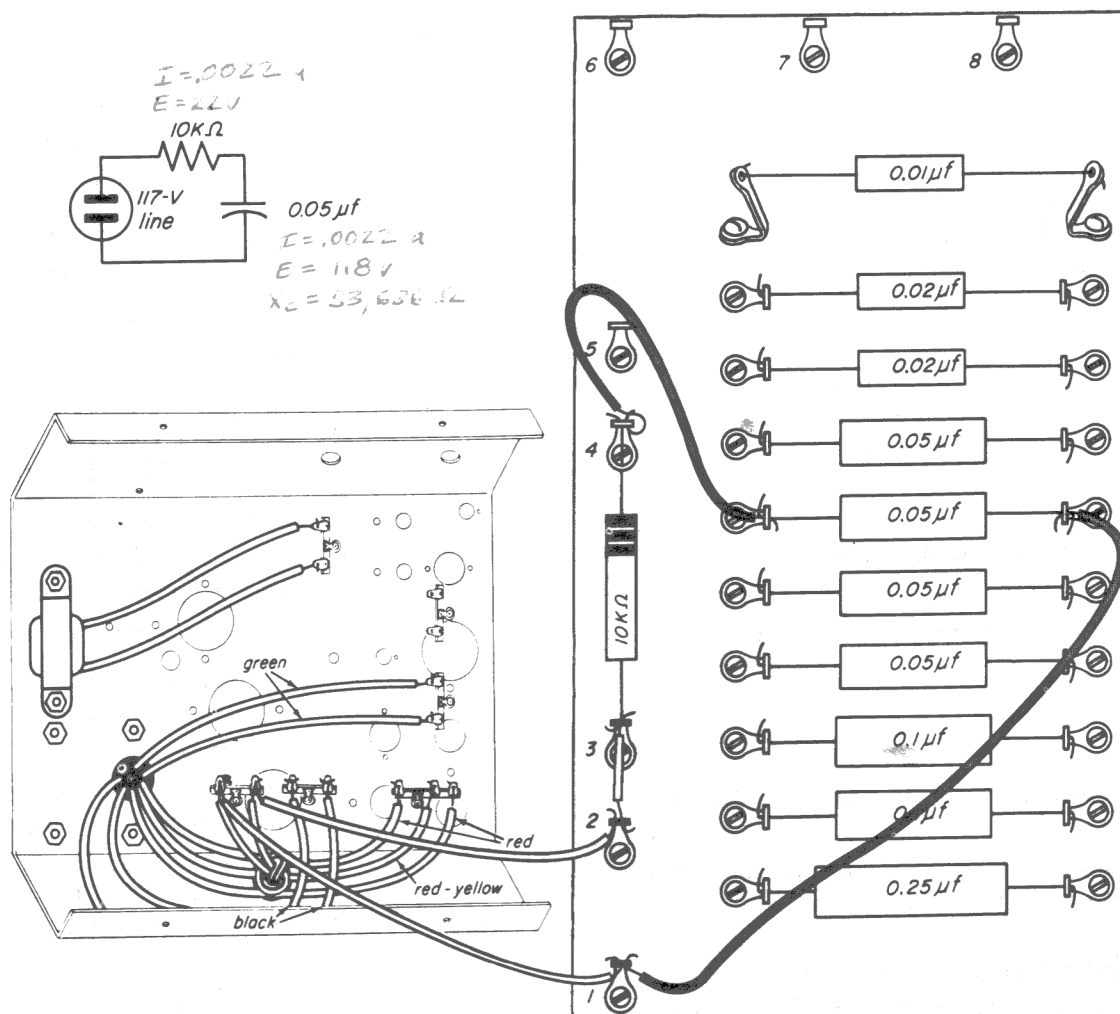


Fig. 15-10

$$C = \frac{159,000}{f \times X_C} = \frac{159,000}{60 \times 33,636} = .0041 \mu f$$

Record the answer here:

.0041 μf

Compare the value of capacity that you calculated with the value marked on the capacitor. As you know, the capacitive reactance decreases as the capacity increases, so they are *inversely proportional*. (When one value increases as another decreases, we say that they are inversely proportional. This is just the opposite to the way in which inductive reactance increases; inductive reactance increases as the inductance increases. (We say that they are *directly proportional*.)

Discussion. The results that you should obtain in this experiment are approximately as follows:

Voltage across the resistor	20 volts
Voltage across the capacitor	106 volts
Current in the series circuit	0.002 ampere
Capacitive reactance	53,000 ohms
Capacitance	0.05 μf

EXPERIMENT 15-7

To study the behavior of capacitors connected in parallel.

Procedure.

Step 1. Connect two 0.02- μf capacitors in parallel and connect the parallel combina-

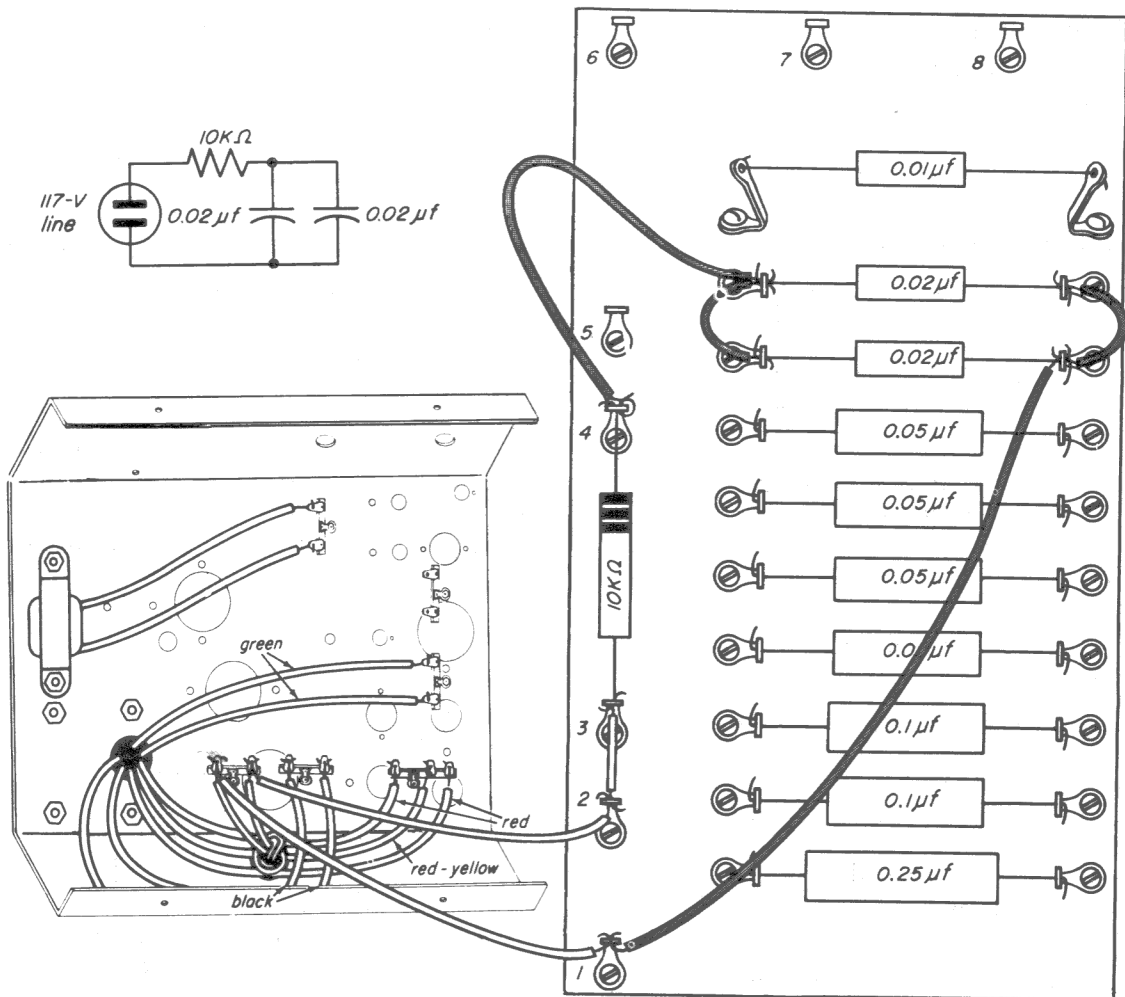


Fig. 15-11

tion in series with the 10,000-ohm resistor, as shown in Fig. 15-11.

Step 2. After checking your circuit, connect the a-c plug to an a-c outlet.

Step 3. Measure the voltage across the resistor and record the value here:

17 volts a.c.

Step 4. Measure the voltage across the capacitors and record the values here:

118 volts a.c.

Step 5. Disconnect the a-c plug from the outlet, and discharge the capacitors.

Step 6. Calculate the current in the circuit.

$$I = \frac{E_R}{R} = \frac{17}{10,000} = .0017$$

Record the answer here:

.0017 amp

Step 7. Calculate the capacitive reactance of the parallel combination:

$$X_C = \frac{E_C}{I} = \frac{118}{.0017}$$

Record the answer here:

69,000 ohms

Step 8. Calculate the capacitance of the parallel combination:

$$C = \frac{159,000}{f X_C} = \frac{159,000}{60 \times 10^3} = 0.00265$$

Record the answer here:

.036 μf

Discussion. Your results for this experiment should be about as follows:

Voltage across the resistor 16 volts

Voltage across the capacitors in parallel 105 volts

Current in the series circuit 0.0016 ampere

Capacitive reactance of the parallel combination 66,000 ohms

Capacitance of the parallel combination 0.04 μf

The capacitive reactance of the two 0.02- μf capacitors in parallel is half that of the single 0.02- μf capacitor; the two 0.02- μf capacitors in parallel act as a 0.04- μf capacitor. This verifies what you have learned in the theory lesson on capacitors, that the total capacity of capacitors in parallel is equal to the sum of the individual capacitors.

EXPERIMENT 15-8

To study the behavior of capacitors connected in series.

Procedure.

Step 1. Connect two of the 0.02- μf capacitors in series and connect them in series with the 10,000-ohm resistor, as shown in Fig. 15-12.

Step 2. When you have checked your circuit, plug in the a-c line cord.

Step 3. Measure the voltage across the

resistor and record it here:

4 volts a.c.

Step 4. Measure the voltage across the two capacitors in series and record it here:

120 volts a.c.

Step 5. Disconnect the a-c power from your circuit and discharge the capacitors.

Step 6. Calculate the current in the circuit:

$$I = \frac{E_R}{R} = \frac{4}{10,000} = 0.0004$$

Record the answer here:

.0004 amp

Step 7. Calculate the capacitive reactance of the series combinations:

$$X_C = \frac{E_C}{I} = \frac{120}{0.0004}$$

Record the answer here:

300,000 ohms

Step 8. Calculate the capacitance of the combination:

$$C = \frac{159,000}{f X_C} = \frac{159,000}{60 \times 300,000} = 0.00088$$

Record the answer here:

.0088 μf

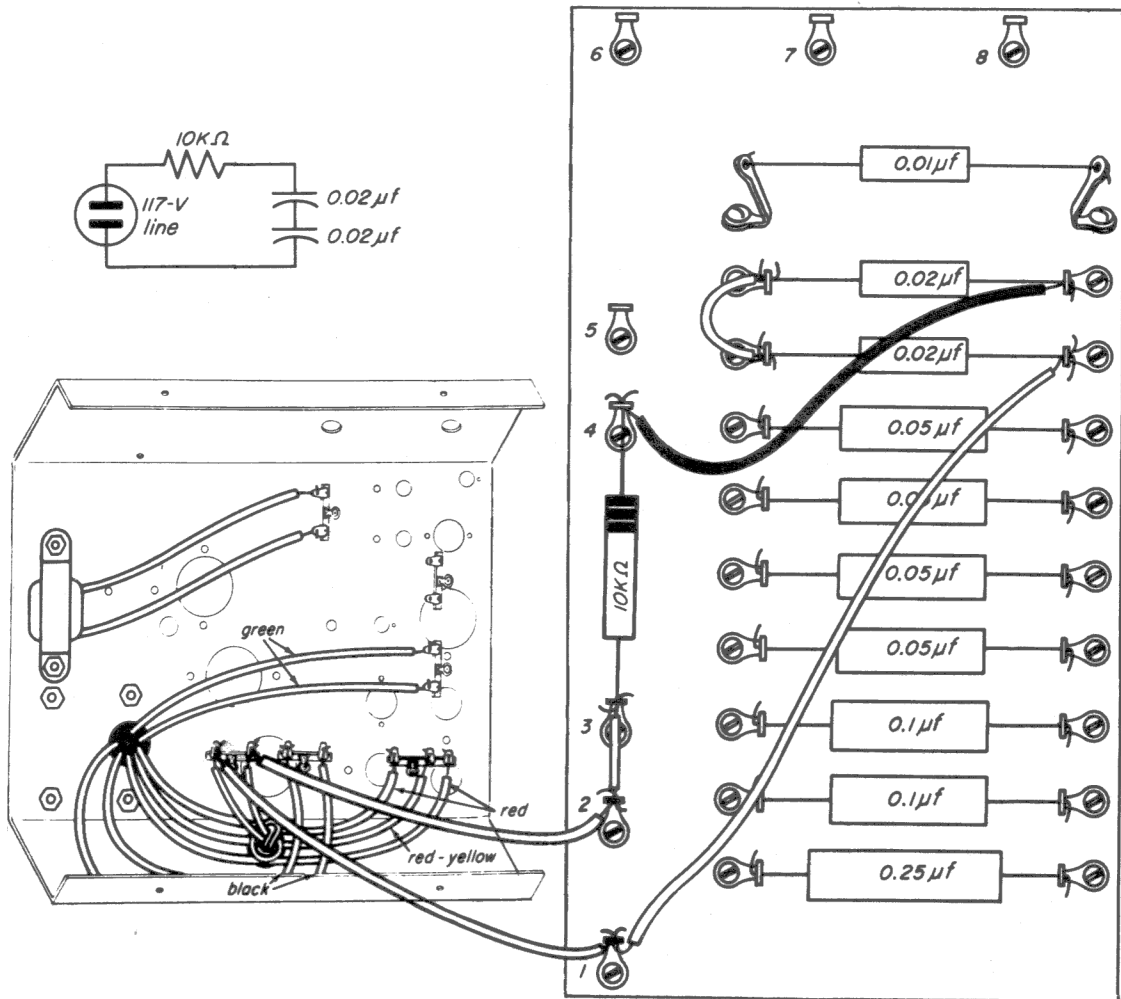


Fig. 15-12

Discussion. The results that you should obtain in this experiment are about as follows:

Voltage across the resistor	4 volts
Voltage across the two capacitors in series	106 volts
Current in series circuit	0.0004 ampere
Capacitive reactance of the series combination	265,000 ohms
Capacitance of the combination	0.01μf

Thus, you see that the capacitive reactance of the two 0.02-μf capacitors in series is twice as great as the capacitive reactance of one of them, and the capacitance of the two 0.02-μf capacitors connected in series is half as much as the capacitance of one of them. This verifies what you have learned in the Theory Lesson regarding capacitors connected in series.

EXPERIMENT 15-9

To find the total capacity of two unequal capacitors connected in series and to learn how a-c voltage divides between them.

Procedure.

Step 1. Connect the 0.01-μf capacitor and a 0.05-μf capacitor in series, as shown in Fig. 15-13. Connect this combination in series with the 10,000-ohm resistor as shown in the drawing.

Step 2. After checking your circuit, connect the line cord to the a-c outlet.

Step 3. Measure the voltage across the resistor and record it here:

volts a.c.

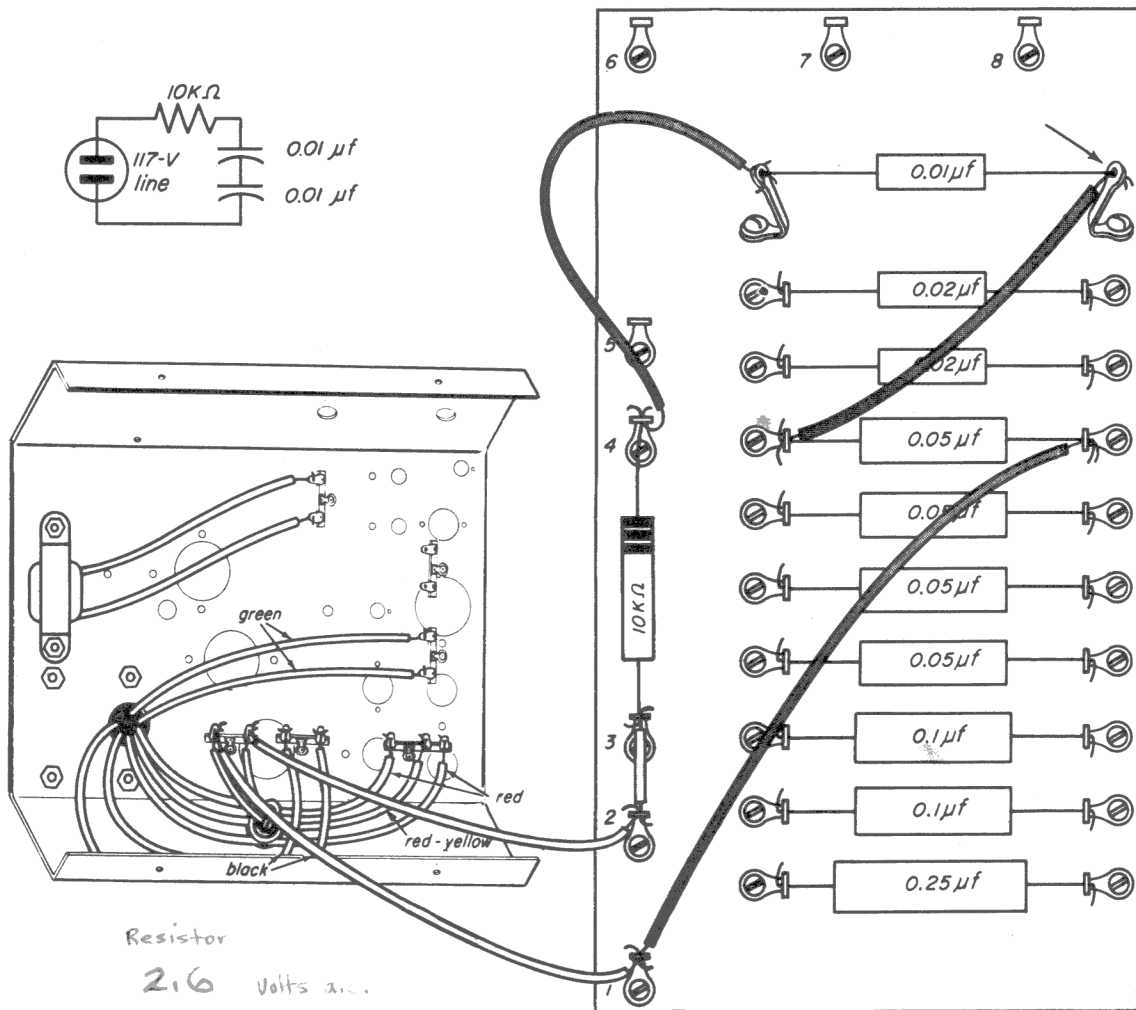


Fig. 15-13

Step 4. Measure the voltage across the 0.05- μf capacitor and record it here:

5 x capacity
1/5 voltage

15 volts a.c.

Step 5. Measure the voltage across the 0.01- μf capacitor and record it here:

1/5 cap
5x v

104 volts a.c.

Step 6. Measure the voltage across the two in series and record it here:

120 volts a.c.

Step 7. Disconnect the a-c power and discharge each capacitor.

Step 8. Calculate the current in the circuit:

$$I = \frac{E_R}{R} = \frac{26}{10,000} = 0.0026$$

Record the answer here:

0.0026 amp

Step 9. Calculate the capacitive reactance of the series combination.

$$X_C = \frac{E_C}{I} = \frac{120}{0.0026} = 46,153.8$$

Record the answer here:

46,153 ohms

Step 10. Calculate the capacitance of the series combination:

$$C = \frac{159,000}{f X_C}$$

Handwritten notes: 159,000, 60,000, 110, 1000

Record the answer here:

Handwritten: 0.008 μf

Discussion. The results that you should obtain in this experiment are approximately as follows:

Voltage across the resistor	3.5 volts
Voltage across the 0.01-μf capacitor	92 volts
Voltage across the 0.05-μf capacitor	18 volts
Voltage across the series combination	110 volts
Current in the series circuit	0.00035 ampere
Capacitive reactance of the series combination	314,000 ohms
Capacitance of the series combination	0.008 μf, approx.

From this experiment, you can see that the total capacity of two unequal capacitors in series is *less* than that of the smaller capacitor. The total capacity of two unequal capacitors in series is given by the following formula:

$$C_t = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{0.01 \times 0.007}{0.01 + 0.007} = 0.0038$$

Handwritten: 0.01, 0.007, 0.0038

The value of the total capacity as obtained from this formula should agree closely with the value that you obtained in Step 10 of the experiment.

The experiment shows that voltage divides between unequal capacitors in series in inverse proportion to their capacities. In other words, the smallest capacitor has the highest voltage across it. Because the 0.01-μf capacitor has one-fifth the

capacity of the 0.05-μf capacitor, it has five times as much voltage across it.

EXPERIMENT 15-10

To study the voltage and impedance relationships in a circuit containing a resistance and capacitance in series.

Procedure.

Step 1. Connect the 0.25-μf capacitor in series with the 10,000-ohm resistor, as in Fig. 15-14.

Step 2. Connect this series circuit to the a-c line, as shown in the drawing.

Step 3. When you have checked your circuit, plug the line cord into the a-c outlet.

Step 4. Measure the voltage across the resistor and record it here:

Handwritten: 98 volts a.c.

Step 5. Measure the voltage across the capacitor and record it here:

Handwritten: 100 volts a.c.

Step 6. Measure the line voltage and record it here:

Handwritten: 120 volts a.c.

Step 7. Disconnect the a-c power and discharge the capacitor.

Step 8. At lugs 1 and 2 of the capacitor board, unsolder the leads from the a-c line. Leave the other ends of these leads connected to the chassis.

Step 9. Calculate the current in the circuit.

$$I = \frac{E_R}{R} = \frac{98}{10,000} = 0.0098$$

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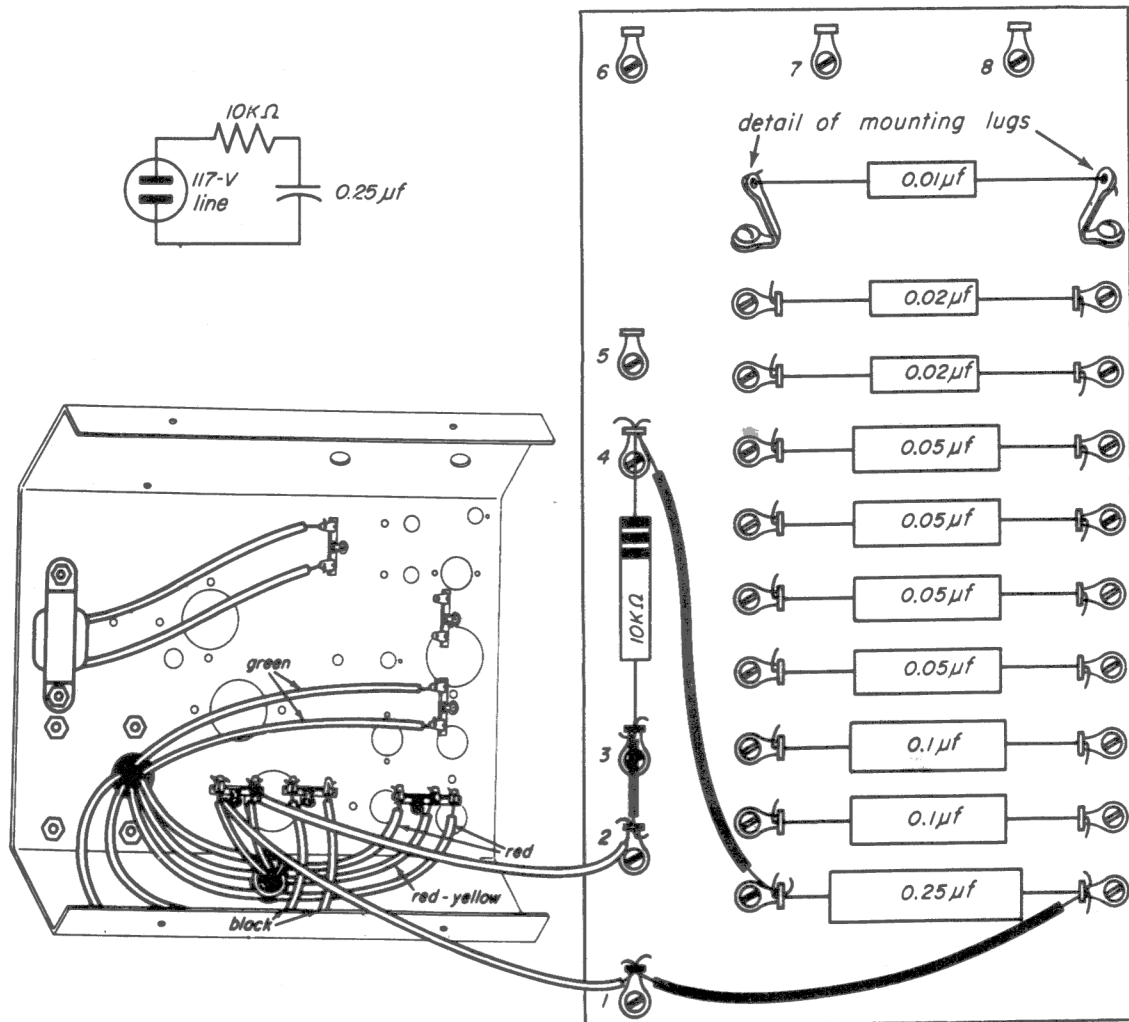


Fig. 15-14

Record the answer here:

0.0088 amp

Step 11. Calculate the X_C of the $0.25\text{-}\mu\text{f}$ capacitor and calculate the impedance of the series circuit:

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{10,000^2 + 11,000^2}$$

Record the answer here:

14900 ohms

Step 12. Calculate the current in the series circuit:

$$I = \frac{E_{\text{line}}}{Z} = \frac{120}{14900}$$

where:

I is the current in the series circuit

E_{line} is the applied voltage (from the power line)

Z is the impedance of the series circuit

Record the answer here:

0.008 amp

Does this agree with the value found from measurements in Step 9?

Discussion. Based on a line voltage of 110 volts, the results that you should have

obtained in this experiment are approximately as follows:

Voltage across the resistor	78 volts
Voltage across the capacitor	78 volts
Voltage across the line	110 volts

The current in the circuit is calculated, as before, by dividing the voltage across the resistor by the value of the resistor in ohms. This gives:

$$I = \frac{E_R}{R} = \frac{78}{10,000} = 0.0078 \text{ ampere}$$

The capacitive reactance of the capacitor is obtained by dividing the voltage across the capacitor by the current through it:

$$X_C = \frac{E_C}{I} = \frac{78}{0.0078} = 10,000 \text{ ohms}$$

The impedance of the circuit cannot be found by adding the 10,000 ohms of the resistor and the 10,000 ohms of the capacitor to obtain 20,000 ohms because they are out of phase. Besides, if this were done, the current in the series circuit would not check with that calculated in Step 9. The current in a series circuit is always equal to the line voltage divided by the total impedance. This would give:

$$I = \frac{E_{\text{line}}}{Z} = \frac{110}{20,000} = 0.0055 \text{ amp}$$

This value does not agree with the correct value of 0.0078 amperes found in Step 9. The current through a resistor is always equal to

the voltage across it divided by the resistance. And, since this is a series circuit, this same current must be flowing in all parts of the circuit.

The impedance is found correctly by taking the square root of the sum of the squares:

$$\begin{aligned} Z &= \sqrt{(10,000)^2 + (10,000)^2} \\ &= \sqrt{2 \times 10^8} = 1.4 \times 10^4 \\ &= 14,000 \text{ ohms} \end{aligned}$$

The current in the circuit can be found by:

$$I = \frac{110}{14,000} = 0.0078 \text{ ampere}$$

This value agrees with the current found in Step 9.

Also, if the voltage across the resistor and the voltage across the capacitor are added arithmetically, that is, $78 + 78 = 158$ volts, it would seem that the voltages in the parts of a circuit add up to more than the applied voltage. This cannot be so. The way to add these voltages is to take the square root of the sum of the squares:

$$\begin{aligned} E_{\text{line}} &= \sqrt{(78)^2 + (78)^2} = \sqrt{6,084 + 6,084} \\ &= \sqrt{12,168} = 110 \text{ volts} \end{aligned}$$

This is the applied voltage as measured in Step 6.

